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Ignition and Growth Reactive Flow Modeling of Recent HMX/TATB Detonation Experiments

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Abstract. Two experimental studies in which faster HMX detonation waves produced oblique detonation waves in neighboring slower detonating TATB charges were modeled using the Ignition and Growth (I&G) reactive flow model parameters for PBX 9501 (95% HMX / 2.5% Estane / 2.5% BDNPA/F) and PBX 9502 (95% TATB / 5% Kel-F binder). Matignon et al. used X1 explosive (96% HMX / 4% binder) to drive an oblique detonation wave into an attached charge of T2 explosive (97% TATB / 3% binder). The flow angles were measured in the T2 initiation region and in steady T2 detonation. Anderson et al. used detonating PBX 9501 slabs of various thicknesses ranging from 0.56 mm to 2.5 mm to cause oblique detonation waves in 8 mm thick slabs of PBX 9502. Several diagnostics were employed to: photograph the waves; measure detonation velocities and flow angles; and determine the output of the PBX 9501 slabs, the PBX 9502 slabs, and the "initiation regions" using LiF windows and PDV probes.

Keywords: Oblique detonation, TATB, HMX, PBX 9501, PBX 9502, Ignition and Growth modeling
PACS: 82.33.Vx, 82.40.Fp

INTRODUCTION

Matignon et al. [1] reported an experiment in which the plastic bonded explosive (PBX) X1 (96% HMX / 4% binder, detonating at 8.75 km/s, drove an oblique shock wave into an adjacent charge of T2 (97% TATB/ 3% binder). The shock initiated detonation in the T2 charge, which has a detonation velocity of 7.75 km/s. Flow angles of 42˚ during the initiation of the T2 and 62˚ after the T2 detonation were measured. Anderson et al. [2-4] recently published the results of five experiments in which 0.56 to 2.5 mm thick detonating slabs of PBX 9501 (95% HMX/ 2.5% Estane/ 2.5% BDNPA/F) produced oblique detonation waves in 8 mm thick slabs of PBX 9502 (95% TATB / 5% Kel-F). Figure 1 shows the experimental geometry used. The set-up consists of: an RP-2 detonator; an 8 mm thick Composition B booster used to initiate both the PBX 9510 and PBX 9502 simultaneously; and a 130 mm by 150 mm PBX 9501/PBX 9502 slab. The breakout face was a 8 mm thick layer of PBX 9502 and various thicknesses of PBX 9501. Not shown are the LiF windows placed on the mid points of: the PBX 9501 surfaces; the PBX 9502 surfaces: and the "initiation regions" where the oblique shock waves from the PBX 9502 detonation waves initiate the PBX 9502 charges. The LiF windows were used with the PDV technique to measure the interface particle velocities between the windows and the reacting explosives. Several other techniques were also used to photograph the detonation waves and measure their detonation velocities. Both of these unique experimental geometries are modeled using the I&G model detonation parameters for PBX 9501 and PBX 9502 in this paper.

THE IGNITION AND GROWTH REACTIVE FLOW MODEL

The Ignition and Growth reactive flow model uses two Jones-Wilkins-Lee (JWL) equations of state (EOS's):

$$p = A\, e^{-R_1 V} + B\, e^{-R_2 V} + \omega \square C_v T \qquad (1)$$

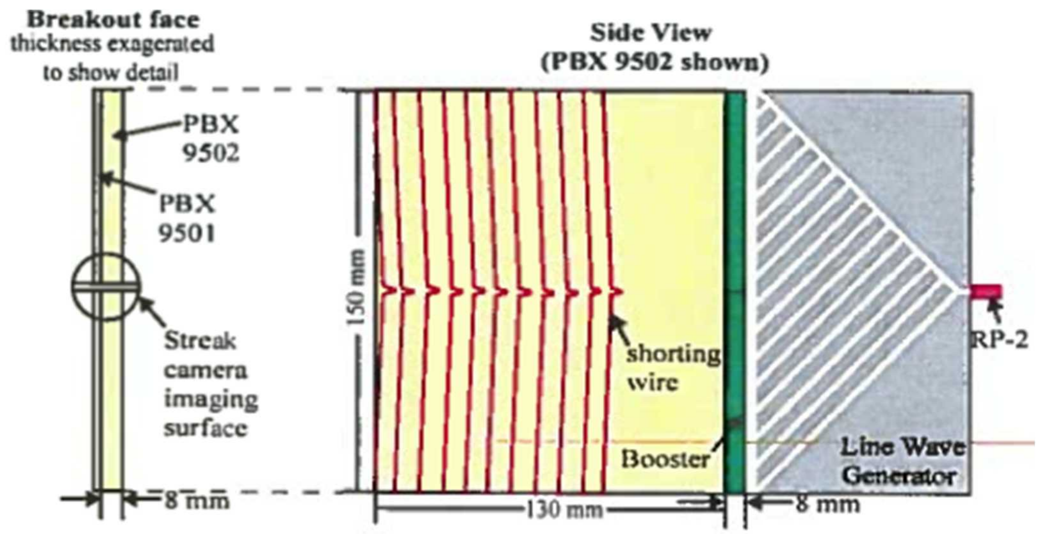

Figure 1. The PBX 9501 / PBX 9502 slab detonation experiment of Anderson et al.

where p is pressure, V is relative volume, T is temperature, ω is the Gruneisen coefficient, C_v is the average heat capacity, and A, B, R_1 and R_2 are constants. These EOS's are fitted to unreacted Hugoniot and reaction product Hugoniot data. The three-term reaction rate equation is used:

$$dF/dt = I(1 - F)^b(\rho/\rho_0 - 1 - a)^x + G_1(1 - F)^c F^d p^y + G_2(1 - F)^e F^g p^z \qquad (2)$$
$$0<F<F_{igmax} \qquad 0<F<F_{G1max} \qquad F_{G2min}<F<1$$

where F is the fraction reacted, t is time in μs, ρ is the current density in g/cm^3, ρ_o is the initial density, and p is pressure in Mbars. I, G_1, G_2, a, b, c, d, e, g, x, y, z, F_{igmax}, F_{G1max}.and F_{G2min} are constants. Pressure and temperature equilibration between the two phases are assumed.

The PBX 9501 and PBX 9502 unreacted and reaction products JWL EOS's have been fit to a great deal of experimental data. The PBX 9502 charges undergo prompt detonations initiated by the Composition B boosters so previously published I&G parameters are used [5]. The I&G PBX 9501 detonation parameters are listed in Table 1. The thin PBX 9501 slabs have significant detonation velocity decrements from the Chapman-Jouguet (C-J) value. Anderson et al. [2-4] measured the detonation velocities for the five slab thicknesses: 0.56; 1.14; 1.55; 2; and 2.5 mm. A comparison between the experimental and calculated PBX 9501detonation velocities is shown in Fig. 2. The PBX 9501 model assumes that 90% of the chemical energy release is released in about 20 ns, and the remaining 10% is released in 80 ns to simulate the slower formation of solid carbon particles. Similar reaction rates were used

Table 1. Ignition and Growth model parameters for PBX 9501 at an initial density of ρ_o = 1 .835 g/cm^3

Unreacted JWL EOS	Product JWL EOS	Reaction rate parameters
A = 9522 Mbar	A = 16.689 Mbar	I = 7.43e+11 μs^{-1} a = 0.0 x = 20.0 b = 0.667
B = -0.05944 Mbar	B = 0.5969 Mbar	F_{igmax} = 0.02 F_{G1max} = 0.9 F_{G2min} = 0.9
R_1 = 14.1	R_1 = 5.9	G_1 = 800 $Mbar^{-3}\mu s^{-1}$ c = 0.667 d = 0.111
R_2 = 1.41	R_2 = 2.1	y = 3.0
ω = 0.8938	ω = 0.45	G_2 = 30 $Mbar^{-1}\mu s^{-1}$
Cv = 2.7806e-5 Mbar/K	Cv = 1.0e-5 Mbar/K	z = 1.0
To = 298K	Eo = 0.102 Mbar-cm^3/cm^3-g	e = 0.667 g = 0.667

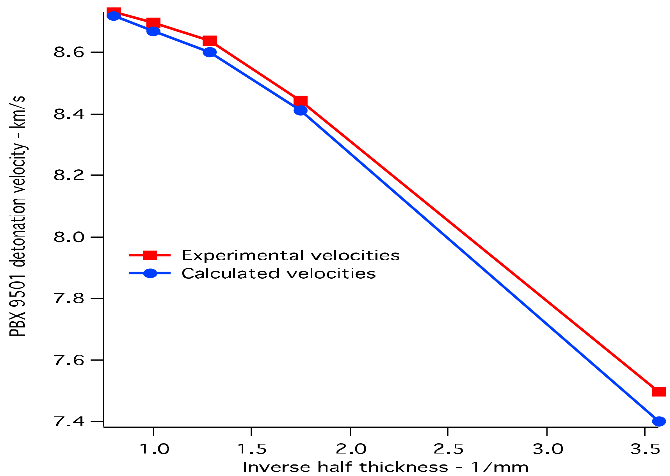

Figure 2. Experimental and calculated PBX 9501 detonation velocities versus inverse half thickness

to calculate the cylindrical rate stick data for PBX 9404 [6]. At the 1.55, 2.0, and 2.5 mm thicknesses, the PBX 9501 detonation velocities are > 8.6 km/s. At 1.14 mm, it is 8.44 km/s. At 0.56 mm, it equals that of PBX 9502.

COMPARISONS BETWEEN EXPERIMENTS AND CALCULATIONS

The calculated angles using the PBX 9501 and PBX 9502 parameters were very close to the measured angles of 42˚ and 62˚ in the Matignon et al. experiment. Anderson et al. reported angles of 43 – 46˚ between the PBX 9501 and the "initiation region" for the three high PBX 9501 detonation velocity experiments. The I&G calculations yielded angles of 43˚, 45˚, and 47˚ for the 2.5, 2, and 1.55 mm thick PBX 9501 slabs, respectively. The 0.56 mm thick PBX 9501 slab and the PBX 9502 have the same detonation velocity with no "initiation region." The slower detonation of the 1.14 mm PBX 9501 slab produced a weaker oblique shock wave with a larger angle (53˚ to 61˚) that changed as the "initiation region" spread. The calculated angles in this "initiation region" changed from ~50˚ to ~60˚. Thus the calculated flow angles for the TATB "initiation regions" and detonation waves agreed with measurements.

The 1.55 mm. 2 mm. and 2.5 mm PBX 9501 detonation waves produced ~1 mm thick "initiation regions" in which oblique reactive shocks traveled through the 13 cm long slabs. Figure 3 shows calculated fringes of pressure and fraction reacted for the various regions produced by the 1.55 mm thick PBX 9501 slab. For the 1.14 mm PBX 9501 slab, the "initiation region" spread across the PBX 9502 slab, causing failure of detonation after 9 cm of propagation [2-4]. Figure 4 shows the pressure fringes in the PBX 9501 "initiation region," and the PBX 9502 just before the PBX 9501 detonation wave reached the LiF window after propagating 13 cm. The light blue "initiation region" spread over most of the PBX 9502, whose detonation thickness shrank to 2 mm as it failed to detonate. The failure thickness for an unconfined PBX 9502 slab is 3.5 mm, and, for an aluminum confined slab, it is 2 mm [7]. The experimental and calculated PDV records of the explosive/LiF interfaces and the three explosives regions are shown in Fig. 5 (PBX 9501 regions), in Fig. 6 (PBX 9502 regions), and in Fig. 7 (initiation regions). Figure 5 shows all detonation waves for the 5 PDV probes centered on the PBX 9501 slabs. Figure 6 shows that all of the PBX 9502 slabs detonate, except for the one adjacent to the 1.14 mm thick PBX 9501 slab. In this case, the PBX 9502 wave failed and only the remaining weak shock wave reached the LiF interface. Figure 7 shows a detonation wave in the "initiation region" for the 0.56 mm PBX 9501 experiment, in which PBX 9501 and PBX 9502 detonated at the same rate. The other 4 thicknesses produced weaker shock waves followed by reactions in the "initiation regions." The weakest of the 4 shock induced reactive flows was produced by the 1.14 mm thick PBX 9501. The amplitudes of the experimental and calculated PDV records agree well.

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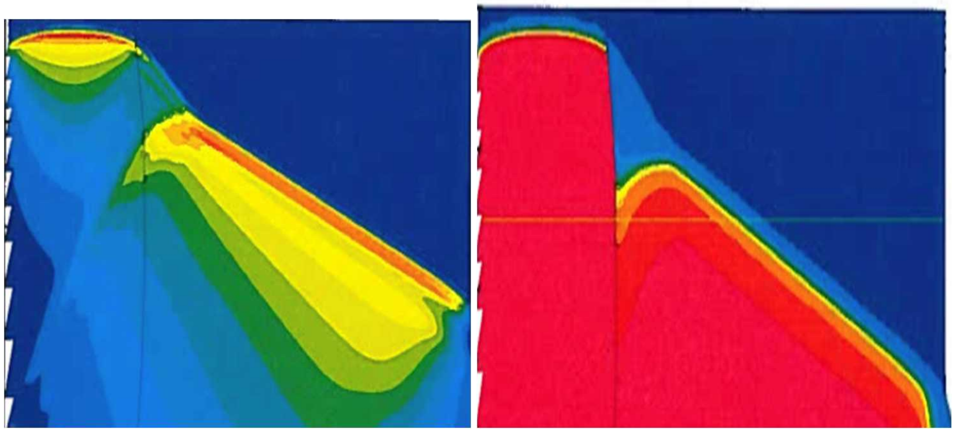

Figure 3. Pressure (left) and fraction reacted (right) fringes for detonating 1.55 mm thick PBX 9501 and PBX 9502. The maximum pressure is ~40 GPa (red) for PBX 9501 and ~33 GPa (orange) for PBX 9502. The "initiation region" is the curved blue/green (left). The fraction reacted varies from zero (blue) to one (red).

Figure 4. Pressure contours in PBX 9501 (left), "initiation region" (center), and PBX 9502 (right) for the 1.14 mm PBX 9501 slab experiment just before impact of the PBX 9501 detonation wave with the LiF window

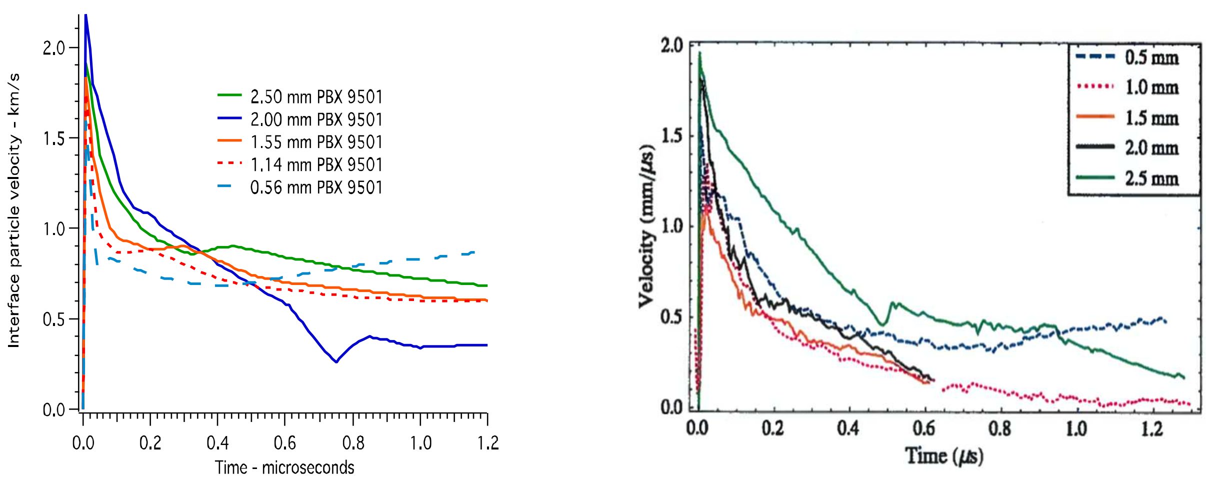

Figure 5. Calculated (left) and experimental (right) interface particle velocities for the PBX 9501 regions.

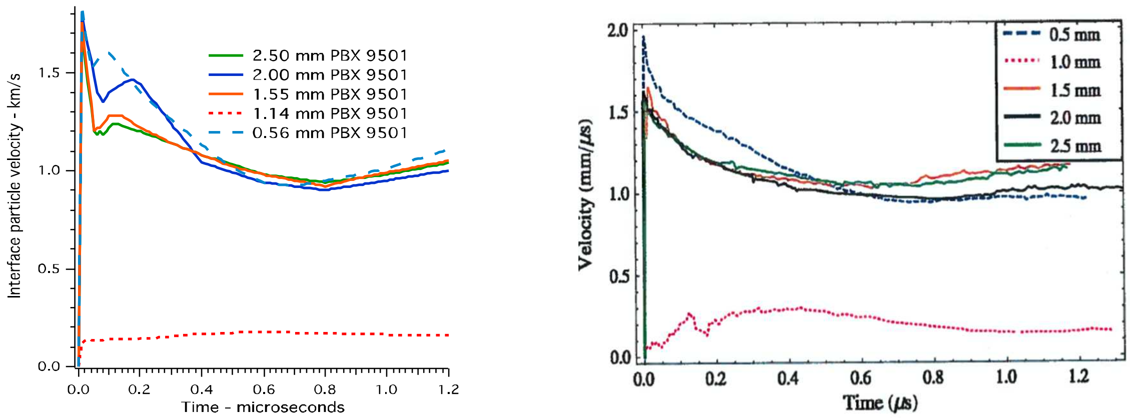

Figure 6. Calculated (left) and experimental (right) interface particle velocities for the PBX 9502 regions.

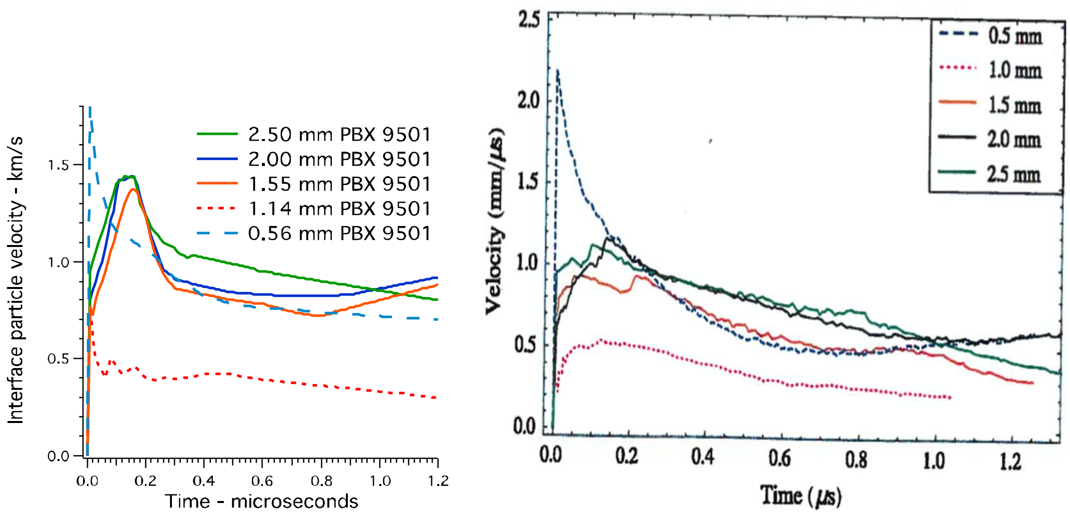

Figure 7. Calculated (left) and experimental (right) interface particle velocities for the "initiation region

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